Big Data Processing and Stochastic Optimization for Grid Monitoring, Control, and Wind Integration

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Introduction

The future energy cyber-physical systems are envisaged to integrate more renewable sources and leverage advanced information and communication technologies to improve grid operations and planning. For example, at wind farms, measurement data of individual turbine's power output at high temporal resolutions facilitates wind power generation analysis and forecast. Massive amounts of more detailed data collected from networked measurement devices provides great opportunities for enhanced situational awareness. On the other hand, it also raises new challenges for the effective extraction of relevant information from massive data so as to support decision making. Under increasingly dynamic and uncertain conditions of the power grid with increased renewable penetration, new computational methods are necessary for efficient management of massive data. New algorithms for data fusion, data mining and data analytics have to be developed based on deeper understanding of the spatial and temporal dynamics of power systems.

Big Data Processing for Wind Farm Generation Forecast

Under a data analytics framework, a support vector machine (SVM) enhanced Markov model is proposed, based on machine learning, graphical learning, and sptaio-temporal analysis for data processing of wind farm generation forecast. The design of the SVM enhanced Markov model consists of two major steps: the design of finite-state Markov chains and the design of wind ramp pattern classifiers based on SVM. Multiple finite-state Markov chains that take into account the diurnal non-stationarity and the seasonality of wind generation are first developed to capture the fast fluctuations of small amounts of wind generation. To capture the wind ramp dynamics, SVM is employed based on one key observation from the measurement data that wind ramps always occur with specific patterns (reflected in the past observations). The SVM can be utilized to forecast wind ramps based on the observed pattern. Further, to capture the diurnal non-stationarity and the seasonality of wind generation, multiple SVM classifiers are used and each of them is associated with a state in each Markov chain. Then, the forecast by the SVM is integrated into each finite-state Markov chain. When forecasting the wind generation, the proposed SVM enhanced Markov model dynamically "adapts" a transition probability matrix of Markov chains based on the current observations, and therefore can potentially capture the wind generation dynamics.

To efficiently integrate the wind generation, distributional forecasts are required to explicitly manage the uncertainty. One of the key advantages of distributional forecasts is that it enables system operators to maintain an acceptable level of risk. Along this line, distributional forecasts based on the proposed SVM enhance Markov model are developed.

For large regions of wind farms, the wind generation forecast in the downstream of wind could significantly benefit from the upstream wind power generation. Enabled by the technological advances in sensing, communications, and computation with affordable costs, spatially correlated wind data could be used for more accurate system-wide short-term wind forecasts. This is potentially applicable to large-scale wind farms, e.g., offshore wind generation. We propose to use spatio-temporal statistical models to leverage the cross-correlation of wind speed at different farm locations for enhanced forecast.

Robust Optimization for Stochastic Unit Commitment with Uncertainty

With increasing penetration into bulk power systems, wind generation has posed significant challenges for reliable system operations, because of its high variability and non-dispatchability. Specifically, one key complication arises in terms of committing and dispatching conventional generation resources, when the short-term forecast of wind farm generation is not accurate. Currently, wind generation forecast for an individual wind farm typically has an error of 15% to 20%, in sharp contrast to the case of load forecast. When the actual wind generation is less than the forecasted value, system operator needs to take corrective actions such committing expensive fast-start generators or load shedding in emergency situation to maintain system security.

To manage the uncertainty of wind power output, stochastic optimization approaches have been studied extensively during the last several decades. These approaches often relies on pre-sampling discrete scenarios generated based on a certain probabilistic distribution. To increase the accuracy of the obtained solution, a large sample size is needed, which results in a problem that is computationally intensive. Recently, robust optimization has gained substantial popularity. Instead of using a probabilistic distribution as in stochastic optimization, robust optimization only requires wind power output within an uncertainty set. This approach searches a solution that can ensure system robustness against all realizations of the uncertain data within the uncertainty set.

Robust optimization approaches provide an effective way to improve system robustness by optimizing the problem under the worst-case scenarios. Therefore, the solutions of the robust optimization approaches are often considered to be very conservative and the total cost tends to be very high, compared with those of the stochastic optimization approaches. To this end, we propose a robust optimization approach for stochastic unit commitment by considering the model uncertainty. Oftentimes, an accurate probability distribution of the uncertain data is assumed in the existing stochastic optimization approaches, and the model uncertainty is ignored. By considering such an uncertainty, our approach can provide a solution more robust than the existing stochastic optimization approaches, and meanwhile less conservative than the existing robust optimization approaches, as more information about the underlying uncertain data are used, beyond the mean and the range of the uncertain data as in the existing robust optimization approaches.

Big data processing of PMU measurements for Grid Monitoring and Control

Big data processing and analytics of synchrophasor measurements collected from multiple locations of power grids by phasor measurement units (PMUs) have the great potentials to enhance various power system operations and control. Compared to SCADA data, the much finer temporal granularity and the precise synchronization make synchrophasor data the most promising tool for dynamic phenomenon monitoring and dynamic security analysis (DSA). The use of PMU measurements for wide area control also has significant potential in providing enhanced control performance. The reliance on a suitable communication channel to transport the signal adds additional complexity in terms of reliability and resilience.

DSA Application

One effective approach to incorporate synchrophasor data into online DSA was proposed [1], which has proven effective when the system operating conditions in online DSA are consistent to the knowledge base prepared offline. However, as power system operating conditions become increasingly dynamic and unpredictable, additional effort has to be made to enhance synchrophasor-based DSA. With this insight, we propose the major requirements for enhanced synchrophasor-based DSA and the potential technical approaches.

1) **Accuracy and robustness**: Enhanced synchrophasor-based DSA should be accurate, and more importantly, should be robust to the operating condition variation and power system topology change and missing synchrophasor measurements.
   Technical approach: Small DTs and the ensemble learning algorithm developed in [2,3] can be utilized to efficiently update the predictive models and the critical decision rules by gracefully incorporating new cases to account for changed situations.
2) **Scalability**: Enhanced synchrophasor-based DSA should accommodate and facilitate the growth of synchrophasor system. First, the new synchrophasor data from newly-deployed PMUs should be seamlessly incorporated. Second, enhanced synchrophasor-based DSA should provide guidance for the placement of new PMUs.
   Technical approach: For the first objective, the random subspace method developed in [3] can be utilized to build small DTs based on new synchrophasor measurements only, and then, these newly-built prediction models can be incorporated by using ensemble learning algorithms. For the second objective, via data-mining, enhanced synchrophasor-based DSA can provide the importance ranking of bus attributes, and thus new PMUs can be deployed at buses that have highest importance.
3) **Distributed implementation and parallel computing**: Enhanced synchrophasor- based DSA should facilitate distributed implementation and parallel computing.
   Technical approach: Small DTs build from the random subspace method [3] can make decisions independently of each other by using subsets of synchrophasor measurements.

Wide Area Control

When PMU measurements are utilized for wide area control the interdependence of the communication channel transporting the signal and the physical infrastructure incorporates a newer layer of complexity in terms of reliability and resilience. The wide area signal could provide enhanced control performance however, the failure of the communication channel could result in the system being vulnerable in terms of reliability.

System resiliency in such situations can be provided by making the physical infrastructure more resilient. This feature can be achieved through novel control designs which utilize multiple input signals including wide area and local signals. The control structure can be designed robustly using modern robust control techniques with multiple input signals. With the wide area signals being available the controller would have superior performance. When the communication channel is lost the controller would still be guaranteed to stabilize the system but the performance of the controller would be slightly degraded [4].

System resiliency can also be enhanced by having redundant communication channels which transmit multiple wide area signals and a hierarchical set of controllers using different wide area signals can be designed robustly. When the channel carrying the control input which provides the best performance is lost a detection algorithm will have to be designed to detect the loss of the signal and when this occurs the controller would have to switched to the controller corresponding to the next wide area signal in the hierarchy which provides the next best performance [5].

These concepts to enhance resiliency will significantly improve power system reliability and performance and will also leverage the nation’s large investment in synchrophasor technology.

Reference

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